N87-20332

# MICROGRAVITY EFFECTS ON ELECTRODEPOSITION OF METALS AND METAL-CERMET MIXTURES

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## ABSTRACT

An experimental system, designed to investigate the potential advantages of electrodeposition in microgravity, is being developed by the McDonnell Douglas Astronautics Company - Huntsville Division and the University of Alabama in Huntsville. It is intended to fly as an Orbiter payload when NASA resumes STS operations. The system will provide power, thermal conditioning, command and control for the production of electrodeposits; system performance data will be recorded for post-flight analysis. Plated metal surfaces will be created using simple electrolytic cells with pure metal electrodes immersed in aqueous electrolytic solutions. Crystalline structure and other properties will be analyzed to identify differences between samples produced in flight and those obtained from ground-based operations.

## INTRODUCTION

Research in the 1800's resulted in formulation of the basic quantitative relationships for electrochemical reactions involved in electrodeposition (electroplating) and led to the establishment of commercial electroplating processes we know today. Michael Faraday[1] wrote the fundamental laws of electrolysis, which govern electrodeposition, in 1833. Fifty-three years later, a young experimenter named Charles Hall[2] discovered the method for creating pure aluminum using an electrodeposition process. He went on to help found the company which became Alcoa. In 1916, O. P. Watts[3], at the University of Wisconsin, published the time-honored ''Watts Bath'' formula for electroplating nickel. The first commercial process for electrodeposition of chromium emerged in 1924. We all benefit from applications of these developments and the many products which involve electrodeposition.

Now, with the opportunity to experiment in space using NASA's Space

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Transportation System (STS), the effects of reduced gravity (microgravity) on electrodeposition carried out over long periods of time can be studied. Recent research using more limited facilities has shown that electrodeposition in a microgravity environment may hold a key to developing superior metal catalysts and surface coatings with special corrosion resistance and hardness characteristics.

In 1976 Grodzka et al[4] reported interesting results from an experiment performed on NASA's Skylab II Mission. It was found that silver crystals grown by an electrochemical copper displacement process were smaller and more perfect than crystals produced on earth.

Ehrhardt[5] found that nickel electroplated on gold in low gravity was impervious to nitric acid. A nickel deposit was produced during six minutes at approximately $10^{-4}$g aboard a British Aircraft Corporation Skylark 7 rocket. Nickel is normally etched by nitric acid. This finding, while not conclusive, indicates that electrodeposition of nickel in microgravity may increase its corrosion resistance.

Riley and Coble[6,7] at the University of Alabama in Huntsville (UAH), used the NASA KC-135 microgravity research aircraft to study the effects of gravity-driven convection currents on electrodeposition. The KC-135 flys parabolic trajectories which provide $10^{-2}$g for approximately 25 seconds. Diffusive flow rates for cobalt electrodeposition systems operated at $10^{-2}$g appeared to be significantly less than flow rates measured for convectionless systems on earth. It was concluded that additional study is needed to substantiate and fully understand this result.

As a continuation and expansion of work already accomplished at UAH, an experimental system is now under development to be flown as part of the NASA G-105 Get-Away-Special (GAS) payload. MDAC's Huntsville Division, one of the founding members of the NASA sponsored Consortium for Materials Development in Space, centered at UAH, is working with the university to accomplish flight hardware design and development. The flight system will be integrated into the G-105 experiment payload at UAH. The GAS facilty, a canister with five cubic feet available for experiment equipment, will be provided through Huntsville's Alabama Space and Rocket Center. This will be the first in a series of exploratory missions planned over the next five years.

## MICROGRAVITY EFFECTS

The advantages of performing electrodeposition in space are as follows:

(1) gravity-driven convection currents in electrolytic solutions will be reduced to a negligible level;

(2) sedimentation of inert particles in electrolytic solutions will be virtually eliminated.

Convection currents, or the lack of them, may have important effects on the formation of crystalline structures in metal electrodeposits. Metal catalysts are used extensively for industrial processes and the efficiency of catalytic activity is a function of crystalline structure. This aspect of microgravity electrodeposition is therefore an important part of the investigation.

The natural (earth gravity) convection currents between a set of electrodes in an electrodeposition system are shown in Figure 1. This picture was made with a laser shadowgraph/schlieren system in an experiment by Riley and Coble[6]. The electrode surfaces are horizontal with respect to the earth's surface. The positive electrode (anode) is located at the top and the negative electrode (cathode) is at the bottom. The ion-rich (heavier) solution at the anode is drifting toward the bottom; ion-depleted (lighter) solution in the vicinity of the cathode is rising toward the top. In clear contrast, no convection currents can be seen in Figure 2 which is a photograph of the same system operating in microgravity ($10^{-2}$g).

Codeposition is the electrodeposition of metal together with an inert constituent such as chromium carbide. The inerts, also called cermets, used in codeposition processes are in the form of particles a few microns in diameter. Codeposition processes are used to produce surface coatings with special abrasive qualities and extra hardness. These processes normally require some means of continuous mixing to keep inert particles from settling out of the electrolytic solution. In microgravity this problem is eliminated. Codeposition will be studied in this experiment with the objective of producing richer, more homogeneous surface coatings.

## EXPERIMENT PLAN

Two processes will be studied in the experiment:

(1) electrodeposition of pure metal;
(2) codeposition of metal-cermet mixtures.

The materials listed in Figure 3 will be used. The metals Ag, Pd, Fe, Ni and Co are of special interest with respect to potential improvements in catalytic performance. Ni and Fe will also be assessed for increased corrosion resistance. The cobalt and chromium carbide mixture provides a hard, anti-friction type surface. Nickel and diamond dust are an effective abrasive combination.

### Electrodeposition of Silver

The electrodeposition of silver illustrated in Figure 4 exemplifies the process to be used for all of the pure metal systems. The electrodeposition cell, containing a silver anode and a gold-plated copper cathode, is filled with a solution of silver cyanide. Electrochemical reactions (electrolysis) begin in the cell when the circuit is closed, placing voltage across the cell, allowing electrical current to flow through the silver cyanide solution.

At the anode, silver metal is oxidized and silver ions ($Ag^+$) enter the solution. At the cathode, silver ions combine with electrons ($e^-$) and are reduced to metal (Ag). The result of this process is the deposition of pure silver on the surface of the cathode.

### Codeposition of Nickel and Diamond

The principles of electrodeposition for a pure metal system also apply to

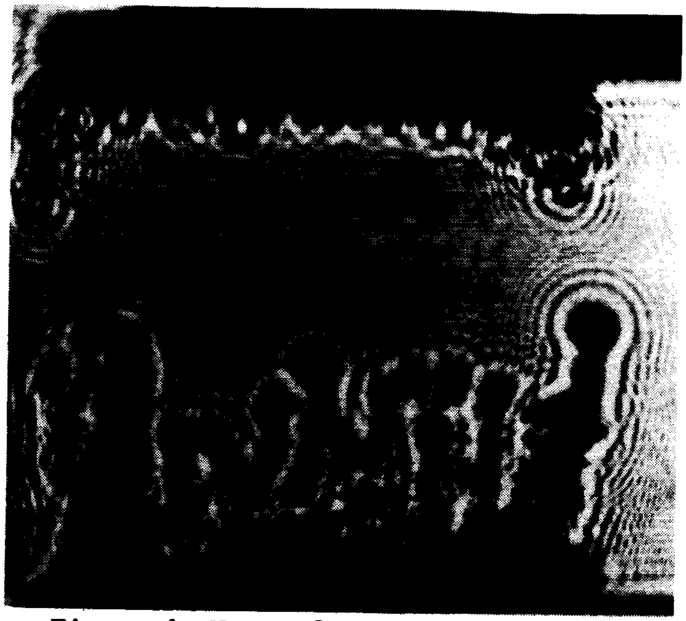

Figure 1. Natural Convection Currents During Electrodeposition

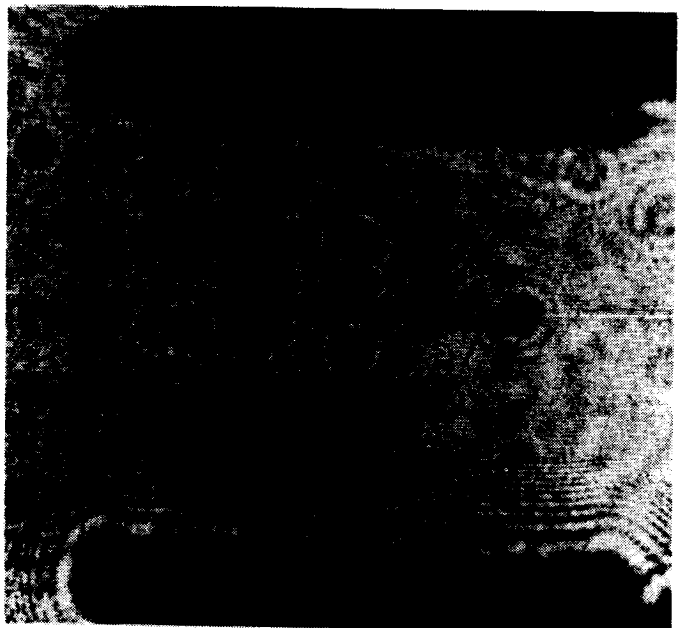

Figure 2. Microgravity Electrodeposition

| ANODE METALS |
|---|
| IRON (Fe) |
| PALLADIUM (Pd) |
| SILVER (Ag) |
| COBALT (Co) |
| NICKEL (Ni) |
| **CODEPOSITION MIXTURES** |
| COBALT + CHROMIUM CARBIDE |
| NICKEL + DIAMOND DUST |

Figure 3. Electrodeposition Materials

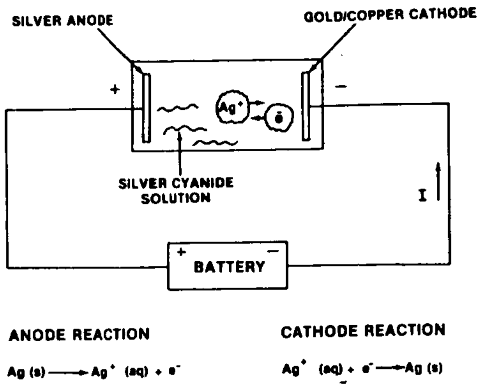


Figure 4. Electrodeposition Cell Concept

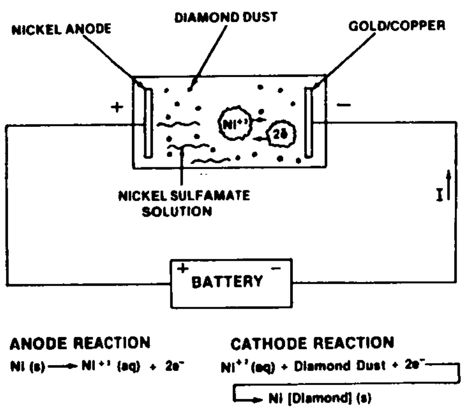


Figure 5. Codeposition Cell Concept

codeposition. Figure 5 illustrates the nickel-diamond dust codeposition cell concept. Here, the minute diamond dust particles (dia. less than $10^{-6}$m) are captured along with nickel atoms at the cathode where a solid deposit of nickel and diamond is formed.

### Measurements and Analysis

Experiment runs will be made on the ground prior to the flight experiment to obtain data for comparison with microgravity results. The basic measurements for both ground and flight runs are electrodeposition cell current, voltage, temperature and operating time. These variables will be measured and recorded throughout electrodeposition operations. Experiment data will be supplemented with Orbiter provided acceleration measurements and experiment activation/deactivation timing.

Analytical methods will include the following:

(1) Comparison of actual and theoretical cell currents to determine if microgravity processes are completely diffusion controlled, i.e., independent of convection or other effects;
(2) Comparison of electrode surfaces, using scanning electron microscopy to identify differences in crystalline structure;
(3) Analysis of codeposits by surface magnification to determine homogeneity and by decomposition to determine richness of mixture;
(4) Exposure of samples to corrosive environments to determine differences in corrosion resistance.

## ELECTRODEPOSITION EXPERIMENT SYSTEM

The system designed for this experiment provides the structures and attachments, power and signal conditioning, data acquisition and thermal conditioning needed for the STS environment and experiment operations. It will be integrated into a GAS payload and installed in the Orbiter payload bay as shown in Figure 6. It occupies one-quarter of the canister and weighs approximately 25 pounds. Power distribution and programmed command and control signals are provided by a control unit located elsewhere in the canister. The control unit is activated via relays in the canister which are operated by a barometric switch during Orbiter ascent and by remote control from the Orbiter aft flight deck during orbital operations. The experiment system contains eight electrodeposition cells which will be operated during a period in the mission when uninterrupted microgravity conditions are expected.

## Functional Requirements

The electrodeposition experiment system provides for the following functional requirements:

(1) operation of eight electrodeposition cells and supporting elements for six hours;

(2) sensing of electrodeposition cell current, voltage and temperature;

(3) generation, distribution and display of digital signals for performance measurement;

(4) photographs of cell operation and displays;

(5) distribution of command and control signals from canister control unit;

(6) stirring of codeposition solutions prior to cell operation;

(7) maintenance of 5°C minimum standby temperature and 20°C minimum operating temperature.

## Configuration and Operation

The major components of the experiment system are illustrated in Figure 7. The system is mounted on an aluminum base plate which attaches to a GAS canister payload mounting plate. The electrodeposition cell and meter assembly contains the eight electrodeposition cells, ten digital displays, two stirring motors, two heating elements and a strobe light. The cells are polished plexiglass to provide a clear view of the interior. The strobe light, not visible in the illustration, provides back lighting for illumination of the cells.

Prior to electrodeposition operations, the stirring motors run for 20 seconds to mix the inert materials in the codeposition cells. A circular magnet, mounted on the shaft of the motor, spins a tiny bar magnet located inside the codeposition cell. This mixes the solution so that the particles will be evenly distributed throughout the cell before beginning the codeposition process.

The camera is a 35mm Nikon which was

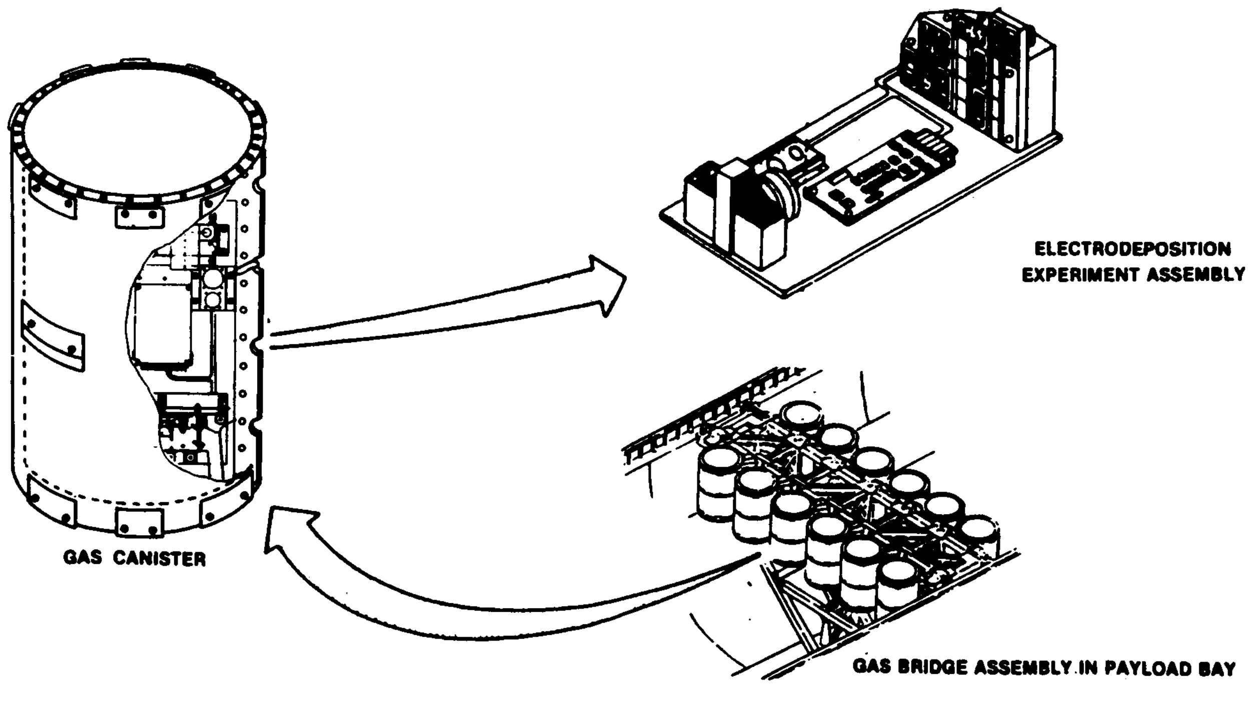


Figure 6. Integrated Experiment Payload

used on an earlier GAS mission. It will photograph the electrodeposition cell and meter assembly 35 times during the experiment. The power/signal conditioning board handles most of the traffic between the canister control unit and the electrodeposition assembly. It provides power inputs for operation of the stirring motors, cells and digital meters. It also generates and distributes digital signals for display and recording of cell performance and temperature.

## Cell Assembly

The electrodeposition cells are stacked in two columns of four each. Behind each clear cell face shown in Figure 7 is a cell made up of parts like those illustrated in Figure 8. The cell body is made from a solid piece of plexiglass. On either end of the body a gasket, electrode plate, power connector plate and end cap go together to seal the electrolytic solution reservoir and provide for power input. The holes in the end cap and cell body are for assembly and mounting.

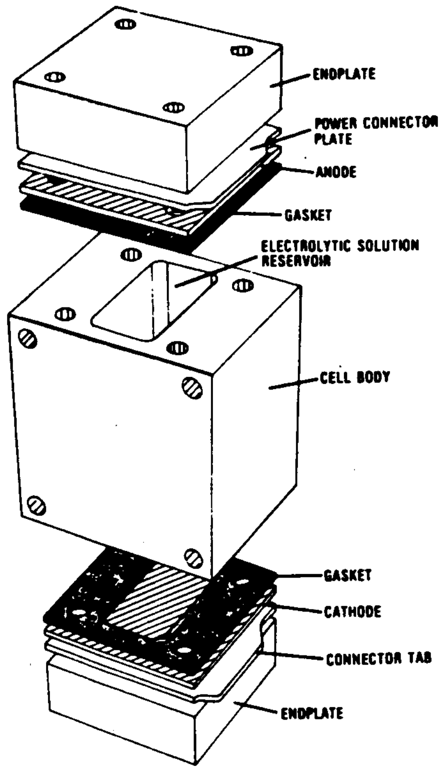


Figure 8. Cell Assembly

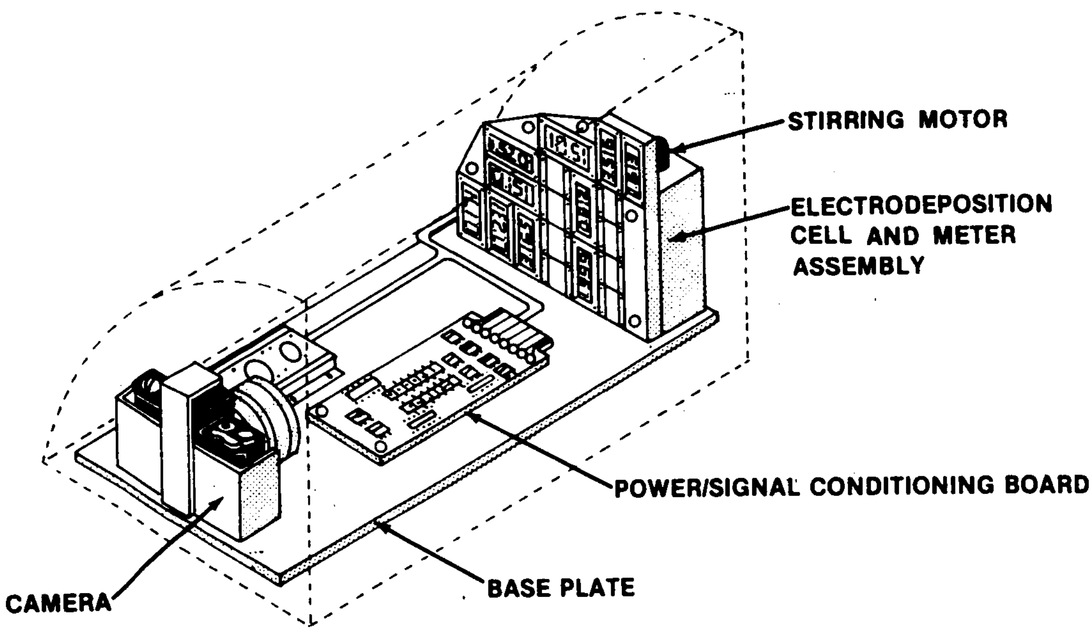


Figure 7. Electrodeposition Experiment Assembly

## FLIGHT PLANS

Experiment system-level testing, GAS payload installation and integrated environmental testing are planned for 1986. Environmental testing will include thermal and vibration tests which simulate STS launch and operational conditions. When STS operations are continued and a flight assignment is granted, the payload will be processed as outlined in Figure 9. The payload will be checked out and installed in a flight GAS canister at Kennedy Space Center (KSC). The canister will be mounted in a GAS bridge assembly for installation into the Orbiter payload bay approximately six weeks before launch. Following the mission the payload will be retrieved from the canister, returned to Huntsville and dismantled for analysis.

## ACKNOWLEDGEMENT

The MDAC-Huntsville Division Space Station Analytical/Design Engineering, Space Station System Engineering and Integration and Spacelab Engineering organizations are working with the UAH Department of Chemistry and Consortium for Materials Development in Space to develop the electrodeposition experiment flight system. Thanks are extended to all of the many people on the MDAC/UAH team who have contributed to the project.

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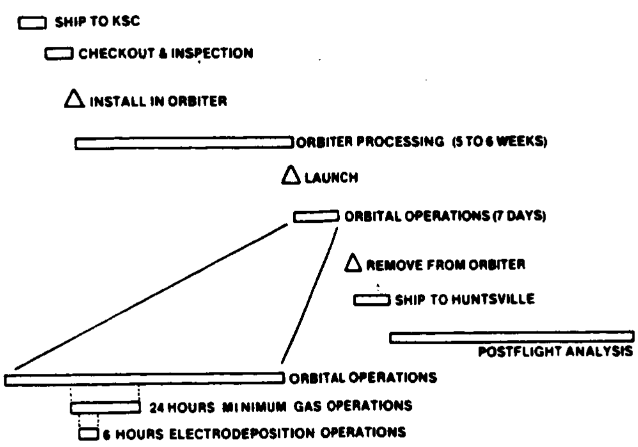


Figure 9. Payload Processing Sequence